Remote Examination of Rock Specimens

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In JPL studies of prospects for post-*Apollo* lunar exploration, methods are being considered for extending the *Apollo* observations into a more complete understanding of the moon's bulk composition, mode of accretion, and thermal history. Based on *Apollo* samples to date, it appears that relatively simple remotely controlled methods may be adequate for characterizing lunar materials found along extended surface traverses. To investigate this possibility, studies and experiments have been made to determine (1) what performance can be expected from a minimum rover-borne system with imaging and sample manipulation, and (2) the advantages conferred by desirable additions, such as close-up color imaging, various types of microscopy, and chemical or mineral analysis using X-rays. Laboratory and field experiments reported in this article support the feasibility of this prospect and identify some characteristics of an automated system required to realize this technique.

Introduction

In JPL studies of prospects for post-*Apollo* lunar exploration, one objective has been to find methods for extending the *Apollo* observations into a more complete understanding of the moon's bulk composition, mode of accretion, and thermal history. With the suite of *Apollo* samples as a starting point, it appears that relatively simple remotely controlled methods may be adequate for characterizing lunar materials found along extended surface traverses. To investigate this possibility, studies and experiments have been made to determine (1) what performance can be expected from a minimum rover-borne system with imaging and sample

manipulation, and (2) the advantages conferred by desirable additions such as close-up color imaging, various types of microscopy, and chemical or mineral analysis using X-rays.

These remote techniques cannot, of course, equal the quality and variety of the analytical methods available on earth. However, because of the great amount of information provided by *Apollo* at isolated surface sites, extension to other regions may be feasible with more limited methods. The object of the tests reported here was to verify this prospect.

Laboratory Imaging Experiments

The first task was to determine the general performance limits of imaging systems required for the later work. By means of simple experiments in the Image Processing Laboratory, it was found that standard closed-circuit television systems available on loan from other JPL programs could be used with minor modifications to simulate the ranges of resolution and other picture parameters considered practical for transmission from lunar rovers (Reference 1). Samples of sand (Figure 1) with various particle sizes and shapes were used to define the limits of acceptable illumination, magnification, contrast, and so forth for identification of the material being viewed. Next, rock samples were examined and it

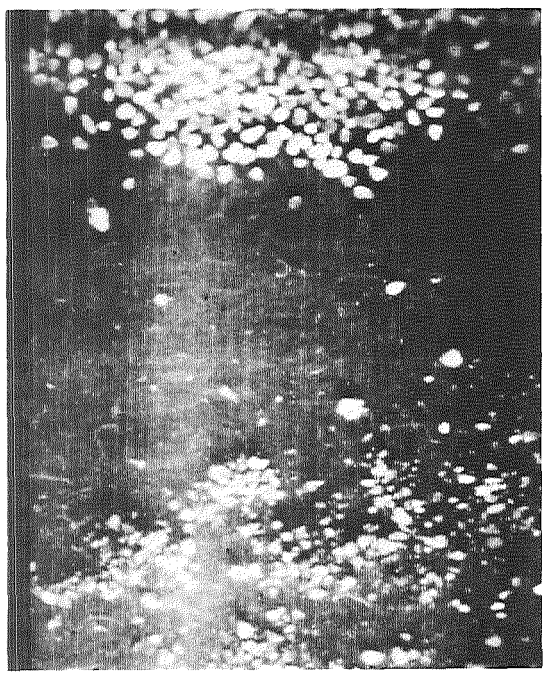

Figure 1. TV image of two sand samples; particle size 100–500 μm

was immediately evident that identification would require three more features:

(1) An ability to rotate the sample, the camera, and the direction of illumination relative to each other.

(2) A size calibration such as a scale in the field of view (or, if an internal reticle is used, a measurement of distance to the sample).

(3) A gray scale in the field of view.

These provisions were easily added in the Science Experiment Test Laboratory (SETL), and a series of identification tests were run using the setup shown in Figures 2 and 3. The samples, mounted on a pan-and-tilt stand and illuminated by the movable collimated light source built for *Surveyor* shadow simulations, were viewed via black-and-white television cameras (with various lenses) by several experienced geologists, petrologists, and mineralogists who recorded their observations, commented on the adequacy of picture parameters such as magnification and depth of field, and attempted to identify the rocks. Then, following the TV session, each observer viewed the samples directly and, if desired, with a hand lens to verify or correct his previous identifications. In this way the limits of required system performance were outlined for various

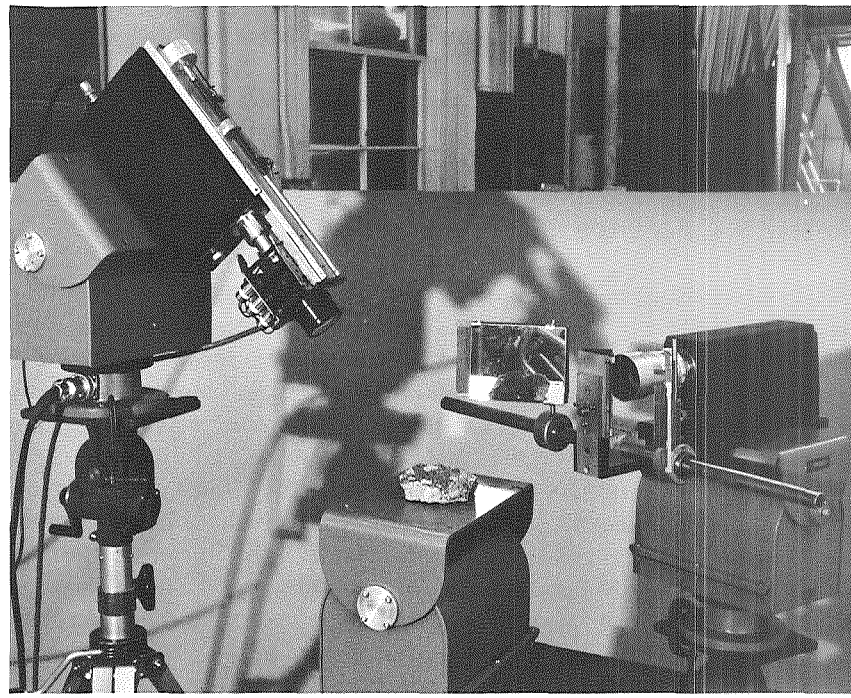

Figure 2. TV cameras with zoom and stereo attachments viewing sample illuminated by movable collimated light source. Pan-and-tilt stands and camera lenses are remotely controlled

Figure 3. Control console for remote manipulators and cameras. Window is curtained to prevent direct viewing during tests

classes of samples. As expected, freshly broken rock surfaces were preferred by all observers; an ability to break open the lunar samples is obviously desirable, particularly when the ubiquitous lunar dust is considered, and is feasible as shown by *Surveyor* experience (Reference 2). The results of this first test series are summarized in Table 1.

The observers were asked to evaluate their own ability at describing rock textures by use of the remote TV system in comparison to their ability with a hand-held specimen. Evaluations were mostly restricted to about five different rock specimens, ranging in type mainly from fine-grained basalt to medium-grained diorite. The specific textural features evaluated included the four principal ones listed by Tyrrell in *Principles of Petrology* (Reference 3). The ratings for the individual petrographers mostly ranged between 75 and 100%; the extreme values, based on individual specimens, ranged from 40 to 100%. The mean values for the principal textures (as averaged for the observers) are: degree of crystallinity, 85%; grain size, 95%; grain shape and crystal-face development, 85%; and intergrain relationships, 80% (Table 1). The average for all petrographers for these four principal textural features was 85%.

The observers' evaluation of their capability at mineral identification via remote TV ranged from 50 to 75% of their ability with a hand-held

Table 1. Quantitative evaluation of the petrographic data obtained by 300-line resolution TV in comparison to a hand-held specimen[a]

Petrographer	Textural features					Mineral identification features	
	Degree of crystallinity	Grain size	Grain shape and crystal face development	Intergrain relationship	Volcanic textures	Number of minerals present	Mineral identification
Number 1	100	100	75	75	75	50	75
Number 2	40 100	95 100	90 100	75 100	— 70	90 60	50 —
Number 3	75	100	75	50	—	—	50
Number 4	100	75	75	75	—	—	—
Number 5	90	100 100	100 80	90 80	—	50	—
Average for individual features	85	95	85	80	75	65	60
Average for major textural features	85						
Overall average	80						

[a]All values to nearest 5%.

specimen using a 10× hand lens. The average value for all petrographers was between 60 and 65%. The average for all seven textural and mineral identification features that were individually rated was 80% (Table 1).

The major difficulty in the evaluation program was inadequate resolution of the first TV system used, so that certain critical mineral phenomena, such as twinning, cleavage, and color differences, were either not visible or were not identifiable. Object resolution based on tests with high-contrast sand grains was approximately 50 μm. Center vertical and horizontal resolution of the TV pictures averaged approximately 300 lines. Substantially better resolution and much higher magnifications were available in the TV systems used in later tests; the data reported here are for the early system, representing about the minimum acceptable from a lunar rover.

Several observers emphatically stated that detailed visual examination should be not only the first but also the primary technique used in analysis of rock specimens on any automated long traverse. It was emphasized that it should be possible to determine 80 to 90% of the petrographic information in most rock specimens—pertaining to textures and to identification of the essential and main accessory minerals—from any technique equal to that of hand-specimen field examination with a 10-power hand lens. A major advantage of visual examination is that many specimens can be examined rapidly; during a lunar or planetary mission, the visual images and other data concerning these rock specimens would be recorded on magnetic tape for later detailed evaluation.

It is readily acknowledged that the study of textures, including all those discussed above, is best done in thin section under a petrographic polarizing microscope. However, the problems involved in the complex preparation of thin sections remotely on the moon, the cost in payload weight, and the probable consumption of substantial mission operations time all weigh against this procedure in the near future. A useful substitute for thin-section examination is the observation of freshly broken rock specimens in reflected light under high magnifications of 40 to 50 power. If the capability of examining mineral fragments under transmitted polarized light is also added, then powerful scientific tools indeed are available for use by the lunar or planetary geologist—tools both for rapid mineral identification and for textural description of the rocks encountered on a traverse.

Field Experiments

Following the tests with isolated specimens, the next logical step was to add the information that is available to an accomplished geologist when he views the surroundings in which the sample is found. On two occasions JPL has experimented with remotely controlled instruments in

the Southern California desert. The purpose of these experiments has been to identify functional and operational requirements for a remotely controlled mobile payload.

The first experiment, reported in References 4 and 5, used a battery of four TV cameras mounted on top of an electronics van (Figure 4). A geologist inside the van was provided an 80-deg field of view on four monitors (Figure 5). A fifth monitor allowed the geologist to direct the operation of the sampling TV camera and various sampling instruments outside the van (Figure 6).

Figure 4. Truck used for field tests, showing controllable array of TV cameras

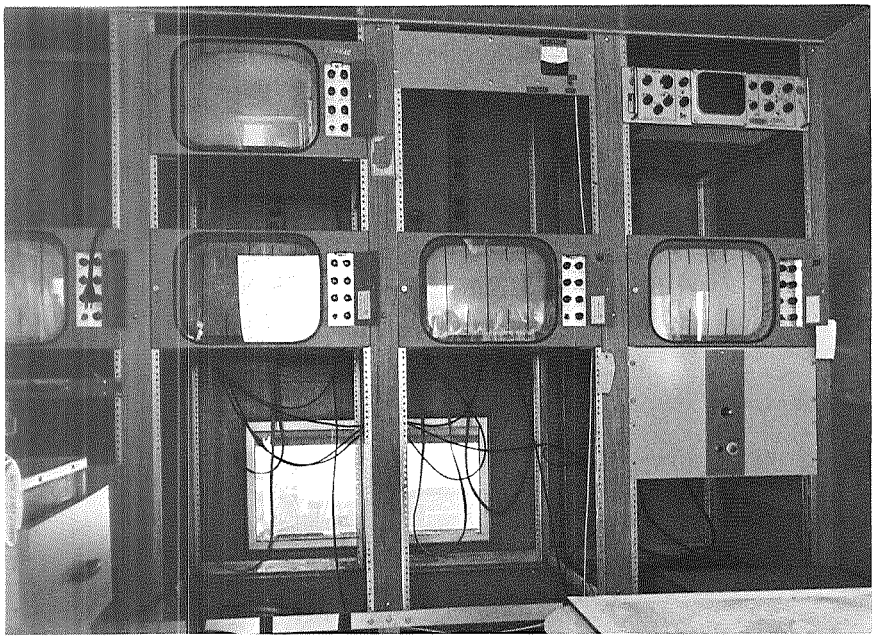

Figure 5. TV monitors inside truck for first test

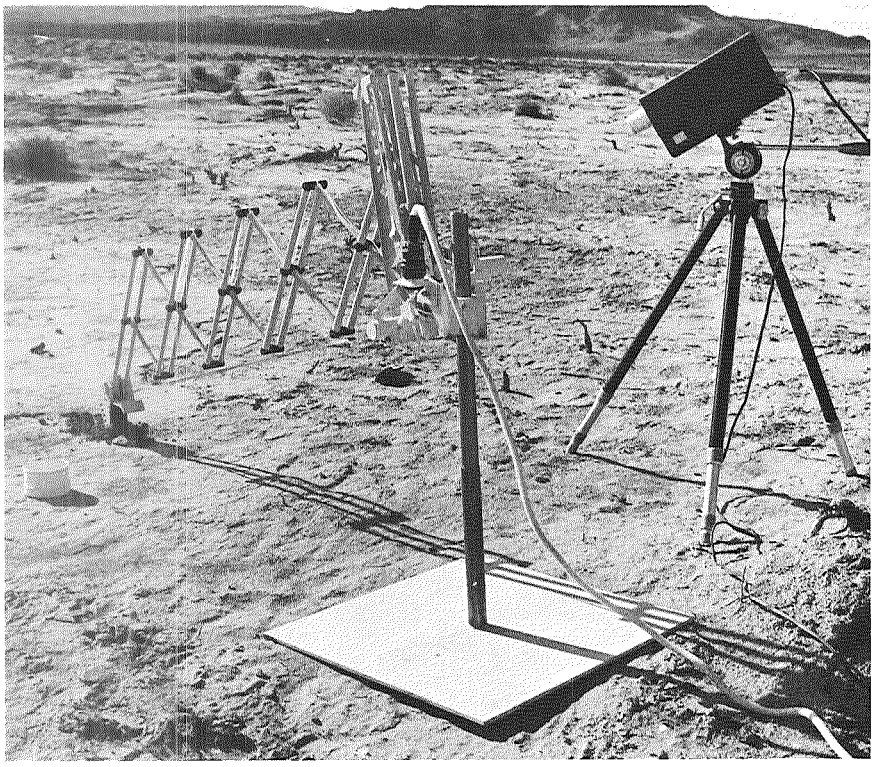

Figure 6. *Surveyor* sampler and sampling camera

Exercises in geological reconnaissance with TV imagery were conducted at 13 stations and sampling exercises at 9. Sample analysis was limited to imagery obtained by the sampling camera (zoom lens included). Conclusions made or confirmed by these exercises are listed in Table 2.

The second experiment, conducted in December 1970, used the same van. In place of TV cameras with overlapping field of view, film panoramas, simulating the images that would be obtained by a photofacsimile scanner on a lunar rover, were used. They were displayed by mounting an illuminated positive transparency above the TV monitors (Figure 7).

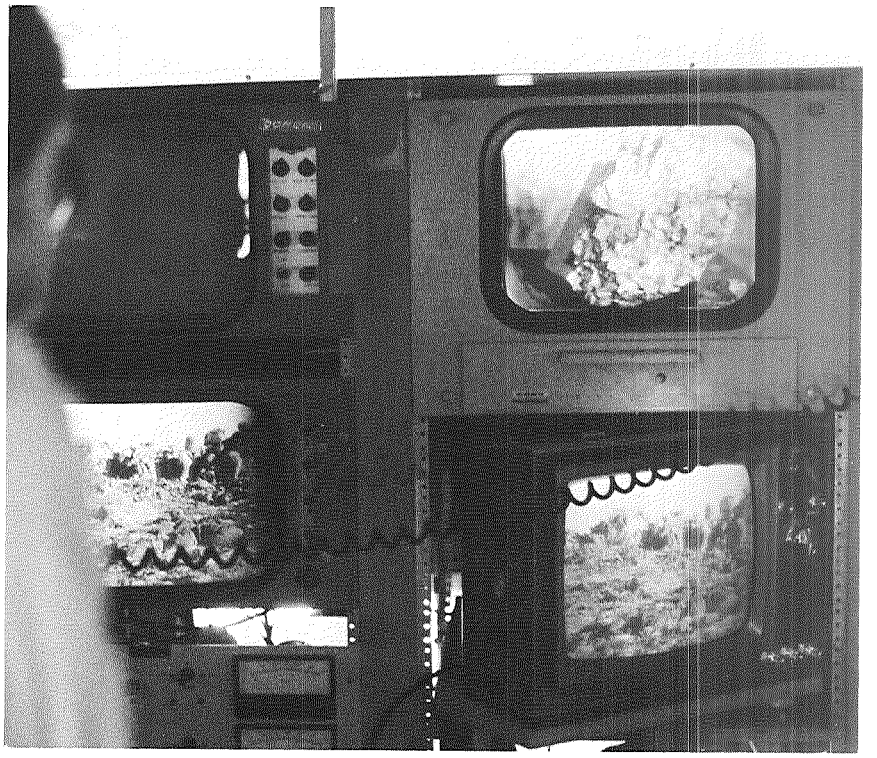

Figure 7. Displays used in second test: (top) panorama, (center) close-up of sample, (bottom) two views of near field

A surveillance TV camera (Figure 8) was mounted at the site from which the film panorama was made. A sample analysis TV camera was installed closer but exterior to the van, both cameras with zoom lenses and controlled remotely from inside the van. Rock specimens were mounted on a pan-and-tilt machine adjacent to the sample analysis camera (Figure 9).

Table 2. Resume of geological conclusions from field data

Operational procedure	Camera parameters	Ground system constraints
1. Direct sampling of surface material is required to supplement the TV data.	1. Some technique of ranging to observed features is required.	1. 360-deg panoramic display of both horizon and near-field should be displayed.
2. Reconnaissance geology requires data on the texture of surface material and either mineral phase data or elemental composition data or both.	2. Some technique of sizing observed features required.	2. High-resolution view of selected areas contained in panoramic view is required.
3. *Surveyor* surface sampler is preferred over drill or auger.	3. Color vision is not particularly important for reconnaissance observations; however, color vision is important in rock and mineral identification.	3. Panoramic view must first be displayed for observations of immediate interest and mapping. A permanent copy of imagery should be made for subsequent study.
4. Properly instrumented rover can perform geological reconnaissance, but not detailed geological mapping.	4. Stereo vision is not required but may be useful in showing relative range of features.	4. The reconnaissance map, with observed geology, will have to be kept up to date with vehicle progress.
5. In addition to data taken at stations, the geologist would like data taken en route between stations.	5. Resolution for observing panoramic display is not particularly critical; however, resolution for examining textures should be able to resolve grains as small as 0.05 mm in diameter.	
6. Geological observations will modify the traverse route and selection of stations.		

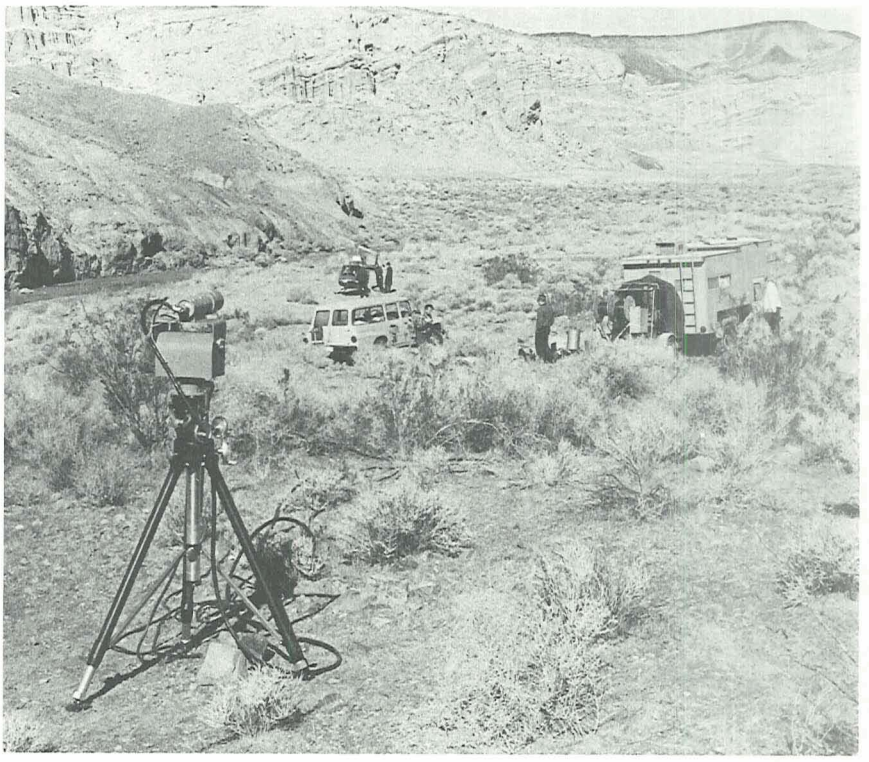

Figure 8. Surveillance TV camera and field test vehicles

To simulate a remote compositional analysis, some samples were analyzed following the field experiment by Mr. Sean Cary at Los Angeles City College using the X-ray diffraction technique. Correlation of petrographic data from the sample analysis camera and the X-ray diffractograms is currently in progress.

A team of three or four geologists in the van (Figure 8) performed geomorphologic analysis on the film panorama, examined distant features via the surveillance camera, selected rock specimens and fines with that camera, and made petrographic analyses of samples. Conclusions on geomorphology, rock units, and structure were then plotted on an aerial photograph of the area. The geologists were not permitted to view the test areas directly, either from the ground or from the air.

At seven stations, covering volcanic terrain, igneous intrusives, and sedimentary sequences, field exercises tended to confirm the earlier conclusions. Final conclusions await completion in the laboratory of the sample analysis. However, certain observations are very clear: Imagery made available to the geologists allowed them to select samples representative of the area. The gross geologic character of most areas

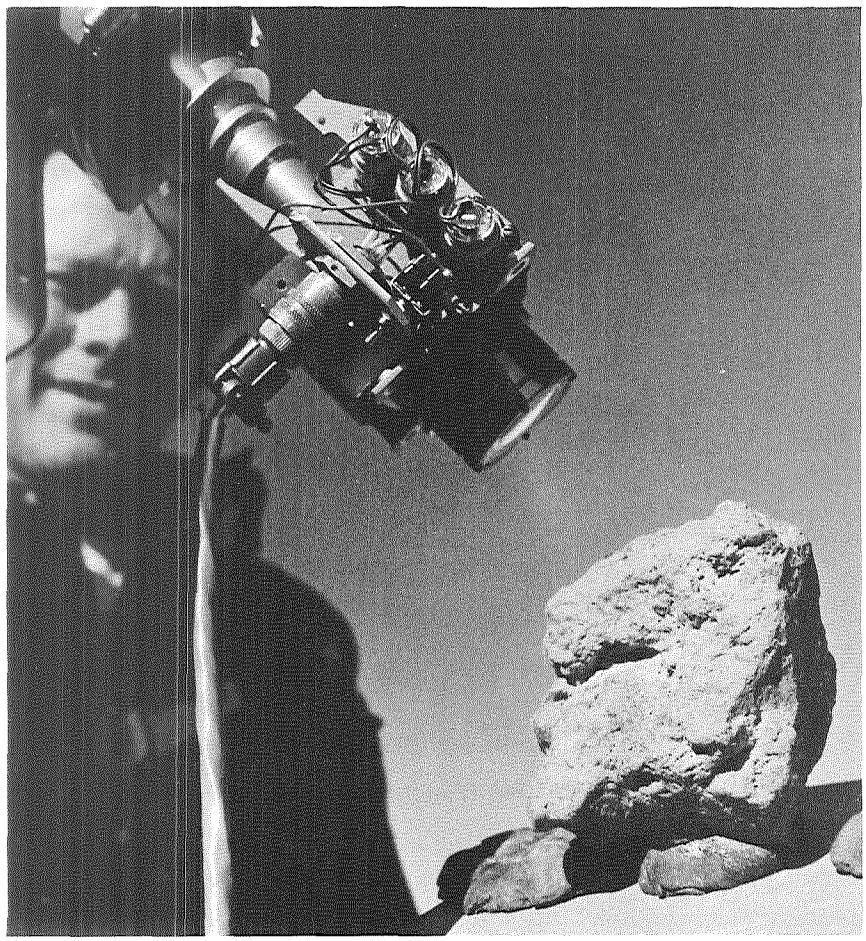

Figure 9. **Close-up camera and sample during second field test series**

was quite evident from the overhead photography and panoramas. Panoramic imagery was found to be very effective in locating sampling sites and providing an integrated view of geological features.

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